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Learning from experience: A survey of existing micro hydropower projects in Ba'Kelalan, Malaysia

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ABSTRACT

Rural electrification to help rural communities improve their quality of life needs to be designed in a sustainable manner with the intention of keeping village culture and environment from eroding. Micro hydropower systems (MHS), especially run-of river schemes, are examples of renewable energy projects that, if managed well, can be socially and environmentally sustainable. This paper presents the results of a field survey conducted in Ba'Kelalan, in Sarawak, Malaysia, where several MHS have been implemented by various funding agencies using different planning mechanisms as well as different design and operational procedures. Quantitative and qualitative analyses were used in a case study comparison of two MHS in Ba'Kelalan based on criteria such as system loads, electricity tariff, the level of community involvement in the project, and the arrangements put in place for maintenance. Several barriers to sustainability were found in the operation and maintenance of the MHS due to a lack of knowledge by unskilled operators. The key lessons learnt from the case study are that sustainable development of MHS requires financial and load distribution management at the beginning of the project, as well as capacity building for both operation and maintenance personnel, as well as the community.

Keywords*: renewable energy; micro hydropower; rural electrification; sustainable development; village power.*

1. Introduction

Two common challenges faced by rural village communities are to improve their quality of life and to reduce the outmigration of young people to urban centres. The solutions to these problems must be sustainable in order to avoid the same types of social and environmental problems, and erosion of culture, that occur in urban areas [1]. Electrification can significantly improve quality of life and renewable energy, although not necessarily intrinsically sustainable, is a good starting point towards sustainable development for a community [2]. Hydropower schemes are one example of renewable energy and "run-of river" micro hydropower systems (MHS) have enabled villages to be supplied with electricity without the social and environmental impacts of larger hydro schemes [3].

Ba'Kelalan is a valley located in remote mountainous terrain in the Borneo Highlands, in the Malaysian state of Sarawak, between latitudes 3° 57' and 4° 04' N and longitudes 115° 36' and 115° 38' E. The Kelalan River flows through this valley and MHS are a logical choice of renewable energy technology based on the available resources. In recent years, a small number of MHS have been installed on the Kelalan River and its tributaries in the valley, by means of relatively ad-hoc approaches without comprehensive planning processes. Three MHS were installed as government projects, and the other 3 were installed by either private business or community-oriented organisations. An assessment of how MHS projects can best meet the aspirations of remote communities is being conducted as a research project at Murdoch University in Western Australia. Ba'Kelalan was chosen as a case study because several MHS projects have been implemented in a short period of time with variations in key factors such as funding and planning mechanisms, design processes and support policies.

This paper presents the results of post-installation surveys of two MHS in the Ba'Kelalan and an assessment of their performance in terms of operation, maintenance and socio-economic benefits. These two systems, one a government scheme and the other community-driven scheme, were selected in order to capture variety in project planning and operation in the area. The survey was used to obtain information to enable a comparison of the two MHS based on a number of parameters, including system loads, electricity tariff, level of community involvement, and maintenance arrangements.

2. Background

2.1 The setting and context of Ba'Kelalan

Most inhabitants of Ba'Kelalan are farmers who cultivate their own land. The six villages in Ba'Kelalan lie close to the Indonesian border and share a common ethnic background across the border with communities in East Kalimantan (see Fig.1). The villages in Ba'Kelalan are not connected to the regional electricity grid due to the remoteness of the Valley. Kerosene, firewood and LPG are used for cooking, while candles and kerosene lamps are used to provide a significant amount of lighting. Where MHS or other renewable energy generators are not installed, electricity for lighting and operating a limited number of appliances, such as television sets, is supplied from small petrol or diesel generators. Kerosene, petrol, diesel and LPG are transported to Ba'Kelalan via a road that, up until 2011, was unsealed. In the wet season, especially during periods of sustained heavy rain, the road often became unpassable leading to irregular supply of fuel and fuel shortages in Ba'Kelalan. The price of these fuels at the point of sale in Ba'Kelalan could increase up to double the normal price. Road construction in 2011, however improved logistics and altered the local energy economy [4].

[Insert Figure 1 here]

2.2 Malaysian Government energy policies relating to Ba'Kelalan

The Malaysian Government has a "uniform cost of living" policy that reimburses transport operators for the costs of transporting essential goods, including fuel, to rural areas [4]. As a result of this policy, fuel delivered to Ba'Kelalan is sold at the same price as fuel in major towns or cities.

In relation to rural electrification, where there are no plans for a village to be connected to the grid within 3 years, the National Ministry of Rural Development may fund a standalone renewable energy generation system to supply electricity to the village, providing that it is more than 10 miles from an 11 kV city grid [5]. The village must cover the cost of house wiring and meters, and users pay for their electricity in accordance with national electricity tariff. The operation and maintenance of this scheme is handled by State Electricity Board. Different states of Malaysia may also fund their own rural electrification schemes. Most remote village electrification projects in Sarawak are funded by grants from the State Government and the systems are then handed over to the community. With this scheme, the community is responsible for the operation and maintenance of the system, which they pay for themselves through local arrangements. The State Government does not charge the community the national electricity tariff.

2.3 Energy resources

Besides hydro, the other main renewable energy resources available in Ba'Kelalan are solar, wind and biomass. The traditional fuel used in Ba'Kelalan is wood, sourced locally from forests surrounding the villages. Firewood is used for cooking rice, boiling drinking water and for space heating (particularly in the mornings). The low number of clear sky days per year, due to significant cloud cover in the valley, and low average wind speeds (less than 4 $m.s^{-1}$ [6]) make both solar and wind energy unviable resources. A small number of other biomass energy resources exist in Ba'Kelalan, including rice paddy straw and cattle manure, but their potential for use in electricity generation is limited due to problems of collection and storage.

MHS is a logical choice for renewable energy technology due to the large number of streams flowing from the surrounding hills into the valley, which is about 945 m above mean sea level [7]. To date, six MHS have been installed on streams in the valley and these are used to supply electricity to five (5) villages. Some of these MHS are small and able to supply only a limited amount of electricity, which is used for lighting and to operate television sets only. As the climate in Ba'Kelalan is tropical monsoonal, rainfall is seasonal and river flows and MHS output decrease in the dry season. In the majority of cases the MHS design was based on spot readings of river flows and future users of the system were not consulted. In such situations, post-installation surveys can be an important source of feedback and evaluation to help improve a system and inform design and planning for additional systems [8, 9]. The research on the Ba'Kelalan MHS projects carried out at Murdoch University aimed to obtain information on resource, loads and user expectations: information which would ideally assist in the planning process. A mixture of quantitative and qualitative techniques was used in gaining information from a number of sources representing several points of view.

3. Methodology

A comprehensive research survey was carried out in stages over a period from 2009 to 2012. The survey used a questionnaire to obtain information on the following:

- Household income and expenditure
- Current energy use pattern

- Current status of micro-hydro systems
- Users' perceived impacts of micro-hydro power on social life
- Views on the prospects for further renewable energy project in Ba'Kelalan

The questionnaire focused on households in the two villages of Buduk Nur and Buduk Bui (see Fig. 1), each of which is connected to a separate MHS. These villages were chosen because of the difference in the way that the two MHS were organised and operate. The MHS in Buduk Nur is funded by the Government and the MHS in Buduk Bui is funded by Rotary Clubs. In Buduk Nur, 49 of 76 households were randomly sampled and in Buduk Bui 21 households were randomly sampled from the 26 households. These sample sizes ensured a 90% confidence level and a 10% margin of error in extrapolating the results to the true population [10]. The head of each household was asked to respond to the questionnaire. The survey also used interviews with village headmen, operation and maintenance personnel, manufacturers and government officials to provide information on MHS in Ba'Kelalan in terms of community involvement, social impact, barriers and issues, design and technical details, funding, strategies and policy. The interviews also sought respondents' overall perspectives on the MHS; their benefits, problems and future prospects.

The detailed research methodology is shown diagrammatically in Fig. 2.

[Insert Figure 2 here]

4. Demographic and energy characteristics of the villages

Information on the socio-economic conditions, patterns of energy use and daily loads were obtained through the questionnaire and interviews.

4.1 Socio-economic conditions

Buduk Bui is a small village and most of the villagers are farmers. There are very few business activities and this contributes to the lack of interest of many young people in living in the village. The situation is slightly different in Buduk Nur since it is the central village for the Ba'Kelalan area and many public service offices (e.g. police, health clinic, Department of Agriculture) and the airstrip are located in Buduk Nur. It is also a hub for business with villages over the border in Indonesia, giving opportunities for young people to set up trade with Indonesian people. Young couples, either from Buduk Nur itself or from other villages in Ba Kelalan, are thus attracted to come and live in this village.

Despite this difference both headmen in Buduk Nur and Buduk Bui, refer to the people living in these villages as "old". This statement is supported by a demographic census held by the Department of Statistics, Malaysia in 2010 [11], which showed there are fewer young people aged 15-40 in rural areas than in urban areas. The headmen reported that very few young people (<30 years) live in the villages as there is no public high school in these villages. There is only one primary school for the entire Ba'Kelalan area while a Bible School in Buduk Aru provides certificate-level training for the *Sidang Injil Borneo* church. Most of the people in these villages can read and write and have completed primary education. Fig. 3 shows that in Buduk Bui the highest education level of the respondents is high school, while in Buduk Nur five of the respondents (10%) had completed either a diploma or a bachelor degree. Almost a quarter (24%) of respondents in Buduk Bui had no formal education, while in Buduk Nur only 4% of the respondents have no education.

[Insert Figure 3 here]

4.2 Income and expenditure

Over two thirds (69.5%) of the respondents from Buduk Nur and slightly less than two thirds (65%) of the respondents from Buduk Bui derived their main income from farming supplemented by income from small business and services. Farming alone provides income for only 26.5% of households in Buduk Nur, which is 10% less than in Buduk Bui. Only 4% of respondents in Buduk Nur did not earn any income from farming. These people have migrated to the village from other areas and do not own land in Buduk Nur.

Rice is the main crop produced in both Buduk Nur and Buduk Bui, with one harvest per year. Approximate incomes were calculated from rice harvest and livestock data with the average annual household income from cropping and livestock estimated to be A$6,872.6 in Buduk Bui and A$4,914.7 in Buduk Nur (See Fig. 4).

[Insert Figure 4 here]

Household expenditure was used as an alternative means of estimating household economies. Fig. 5 shows the average expenditure per person per month varied widely between the households of the respondents. In both Buduk Bui and Buduk Nur, more than half of the people spend A$50 per month and only a few (around 10%) spend more than A$100 per month. Fig. 6 shows that food, energy (fuel, micro hydro, wood, battery, candle, LPG, kerosene), and education capture the bulk of monthly household expenses. Although the proportions of total expenditure spent on each of energy, education and food are similar in both villages, the average monthly expenditure per household in Buduk Nur is almost double that of Buduk Bui.

[Insert Figure 5 and Figure 6 here]

4.3 Current patterns of energy use

In Buduk Bui electricity supplied by the MHS is available throughout the year, while in Buduk Nur the MHS does not operate during the dry season (especially in August) due to low river flows. Table 1 shows the various sources of energy used, together with average monthly consumption figures for typical houses in Buduk Bui and Buduk Nur[1]. The average monthly household consumption of electricity supplied by the MHS in Buduk Bui is around 50% greater than that supplied by the system in Buduk Nur. This is due to power consumption limits imposed by the Micro Hydro Committee (MHC) of each village, which were set up independently to manage the operation and maintenance of the MHS. From interviews with MHC members, a limit of 250 W was placed on households Buduk Bui versus a limit of 100 W in Buduk Nur. Initially these limits were stipulated in agreements between the householders and the MHC, but in 2012 the MHC in Buduk Nur installed current limit devices in households.

[Insert Table 1 approximately here]

The breakdown of monthly expenditure on energy per household is shown in Figure 7 below. The average monthly expenditure on energy by households in Buduk Bui is less than two thirds that of Buduk Nur. Nonetheless, the expenditure on some items such as mowing, rice milling, transportation and cooking are very similar in both Buduk Bui and Buduk Nur. The greatest variation comes in electricity and the use of power tools where average monthly expenditure in Buduk Nur compared to Buduk Bui is about double and almost triple, respectively.

[Insert Figure 7 here]

[1] During the time of year when the MHS are working in each village

4.4 Peak loads and daily consumption

An energy audit was carried out for each household to understand the energy needs and usage patterns of the villagers. The range of appliances used in the audited households included washing machines, refrigerators, freezers, electric kettles, rice cookers, toasters, electric ovens, computers and blenders.

In general, peak loads occurred in the evening (6.00 pm – 9.00 pm) and early morning (5.30 am – 7.30 am) and reached a minimum during the non-peak hours (8.00 am – 5.00 pm and 11.00 pm – 5.00 am). In Buduk Nur, the peak load contribution on the MHS by the combined households was 11.239 kW and the minimum load was 1.801 kW while in Buduk Bui the peak load contribution on the MHS by the combined households was 4.726 kW and the minimum load was 1.021 kW. It was calculated that the load factor in Buduk Nur was 0.4 while it was slightly higher in Buduk Bui at 0.5.

Figure 8 shows the variation in average daily electricity consumption among the surveyed households. The daily consumption for audited households varied between 740 – 6,738 Wh with an average daily consumption per household of 2238 Wh in Buduk Bui, and 324 – 6,920 Wh in Buduk Nur with an average daily consumption per household of 1412 Wh. The majority of respondents in Buduk Bui have daily consumptions of 1000 – 3000 Wh, while in Buduk Nur the majority have daily consumptions less than 2000 Wh. In Buduk Bui only 5% of respondents have daily consumptions less than 1000 Wh while in Buduk Nur it is 31%. On the other hand, the proportion of respondents whose daily consumption is more than 5000 Wh is 14 % in Buduk Bui, and only 6% in Buduk Nur.

[Insert Figure 8 here]

Both committees regulated that each household could only operate lights and a television set. In practice, however, some people tried to plug in other appliances. Common appliances used were washing machine, DVD player, refrigerator/freezer and computer/laptop. In an effort to avoiding overloading the system, the MHC in Buduk Nur introduced current limit devices into households in 2012. This was not effective, however, as many villagers were not happy with the limit and found ways to by-pass the current device. Villagers in Buduk Bui were more compliant with the agreed power limit and learnt to manage their own load by using electrical appliances at separate times to avoid black-outs from overloading the MHS. Households in Buduk Bui, however, tended to leave lights on for 24 hours even though rooms were not occupied, increasing daily load consumption. This action was encouraged by the MHC in Buduk Bui which believed that the households needed to keep up demand in order to match the power supply from the MHS.

5. Micro hydropower in Ba'Kelalan

The following picture of hydropower growth has been assembled from the results of the interviews with village headmen, operation and maintenance personnel, manufacturers and government officials. The first MHS constructed in Ba'Kelalan (the Apple Lodge system) was privately funded and the observed success of this private scheme in terms of increased quality of life and access to low cost electricity triggered interest in further MHS development in the Valley. This prompted the Government to consider this option for its rural electrification objective. The projects in Ba'Kelalan are funded through a range of support mechanisms: government, NGO, community-based and private funding. They also serve a range of purposes, vary in their output capacities and the processes put in place for maintaining and managing them (Table 2.)

[Insert Table 2 approximately here]

5.1 Type of micro hydropower systems

All the MHS installed in Ba'Kelalan are run-of-river systems due to the steep terrain and the inability to construct storage dams of any significant volume. The capacities of the MHS are determined by the pressure head and available flow rates. Fluctuations in flow rates throughout the year therefore have an impact on the amount of power produced. Due to the time and resources involved in obtaining detailed flow readings, the MHS installed in the area were designed on the basis of a relatively small number of spot readings taken during the dry season when the flows are at their lowest.

The other characteristic of MHS in Ba'Kelalan is that they are instantaneous induction turbine micro hydro systems i.e. they have no batteries connected to provide storage. All power produced by the MHS is used to meet household load or is dumped to a resistive load. The lack of storage also means that when instantaneous load exceeds instantaneous power generation, typically during the evenings, consumer demand is not able to be met.

An electrical switching panel is used to distribute the power between the lines and manage the line load. The small capacity of the systems and the concentration of demand in the evenings cause problems for load management. For example, in Buduk Nur, there are 3 lines from the powerhouse. Current limits are set for the individual lines rather than for individual households. The consequence of this is that the whole line goes down when the current limit is exceeded. Such a situation could be caused by a single household, but there is no way to identify which household would need to take corrective action.

5.2 Funding micro hydropower schemes

Four different funding sources have been used for the various micro-hydro projects in Ba'Kelalan: Government, NGO, community and private capital. The systems in Buduk Nur, Long Langai and Long Rusu were funded by the Government, while the MHS in Buduk Aru was funded by the community and another MHS in Buduk Nur was installed as a private investment.

The MHS at the government operated Public Health Clinic in Buduk Nur, was fully funded by the Ministry of Health. Its initial purpose was to electrify the Clinic, but members of the Buduk Nur community subsequently approached the Ministry of Health requesting access to the electricity generated by the MHS. The Ministry agreed to supply sufficient electricity from the scheme. Another MHS, located in Buduk Bui, was funded by a grant from the Rotary Foundation, with the major contributions from Kuching as the Host Club, and Raffles City Rotary Club in Singapore as an International Partner. A total of US$41,500 was raised by Rotary Clubs in Malaysia and Singapore. This project proceeded relatively smoothly from planning to construction. The funding application was submitted in March 2007, the site work began in April 2008 and the project was commissioned in November 2008 [12]. None of the MHS described were set up with electricity supply tariffs for their users. Maintenance costs or capital outlays are considered on a case to case basis.

5.3 Community involvement

The local communities were involved in the planning and construction of all of the MHS in Ba'Kelalan, other than the privately owned one in Buduk Nur, where only a small number of individuals were engaged in the project. The nature and extent of community involvement depends on the type of funding. Most of the community involvement occurred during the civil works, and the communities are also involved in the ongoing operation and maintenance of the systems. In the NGO and community-based projects, the communities were involved in funding, site works, and ongoing operation and maintenance.

In both Buduk Bui and Buduk Nur, the community was involved during the installation phase. Community members contributed their labour in construction and continue to provide operation and maintenance. External funding covered the costs of the equipment, including the hydro-turbine set, electrical switching panel, electrical cable, cement and steel to build the check-dam, and other components required to complete the project. The MHC in Buduk Bui and Buduk Nur each comprise of a chairman, secretary, treasurer, technicians and a number of helpers from the constituent hamlets of the village.

5.4 Operation and maintenance

The villagers are responsible for operation and maintenance (O&M) of the micro-hydro in both Buduk Bui and Buduk Nur. In both villages, daily operations are undertaken by the MHC technicians, who received training directly from the installer. If a problem occurs it is reported to the chairman and if the chairman considers the committee capable of handling the problem, the chairman will call a committee member, called “the expert” in Buduk Nur and “the express” in Buduk Bui, to fix the problem. If the problem requires a number of people, such as clearing the dam or clearing the path along the river, the chairman will invite all of the members of the village as a form of *gotong royong* (voluntary community service). If the problem is not able to be solved by the committee, the supplier of the system is contacted.

External training in O&M was provided in the case of Buduk Nur, and one person from the committee attended one week of training provided by the turbine supplier. The training included MHS operation and pipe installation, but no training was provided on either wiring or distribution. When the supplier installed the electric switching panel and wiring from the turbine to village, some committee members were invited to join on-site training. In Buduk Bui, only on-site training was provided for committee members and included both turbine operation and maintenance and wiring.

In Buduk Bui the committee has not strictly followed the maintenance schedule stipulated in the O&M manual provided by the manufacturer, and their usual approach is to do nothing unless a problem occurs and then to fix the problem. In Buduk Nur there is no maintenance guide and the official approach of the committee is to fix the problems if and when they occur using the knowledge obtained in their training. According to the committees in both villages, the O&M is carried out on a trial and error basis.

5.5 Electricity Tariffs

In Buduk Bui the electricity from the MHS was supplied free of charge in the first few months. Realising that it is a long distance to check or clean the dam; the villagers wanted to pay the people responsible for undertaking this task as well as pay for maintenance of the MHS. Consequently, the committee for the Buduk Bui MHS decided to levy a charge of MYR 5 (A$ 1.70) per month per household (except that of the Pastor) with the monies to be collected and managed by the committee.

The tariff scheme for the Buduk Nur MHS is slightly different. The responsibility for operation and maintenance of the MHS was transferred to the villagers after the Public Clinic in Buduk Nur agreed to share the electricity with them. The MHS in Buduk Nur was commissioned in May 2010 and the villagers used the electricity free of charge until October 2010 when the MHS experienced trouble and a component needed to be replaced. The committee asked all of the villagers, except the Pastor, to make a single special payment of MYR 50 per household with a further levy of MYR 10 (A$ 3.30) per month for 5 months (May-October). One respondent pays MYR 20 per month (double the standard levy) because she runs a business with 3 freezers. The monies are collected and managed by the committee to cover the operation and maintenance costs.

6. Impact of micro hydropower projects

The questionnaire respondents were asked about the impact of the MHS in terms of social cohesion, income and other benefits. Figure 9 shows the social impact of the MHS within the households in Buduk Bui and Buduk Nur. Respondents in Buduk Nur are twice as likely to be engaged in productive activity in their own household compared to those respondents from Buduk Bui. More than one third of the respondents in Buduk Nur reported that they have more entertainment (TV, DVD, radio etc) in their home because of the MHS. In Buduk Bui 14% of the respondents mentioned that they have more interaction with other family members, compared to 11% in Buduk Nur .

[Insert Figure 9 here]

The MHS has also had an impact on social interaction within the community. About a quarter of the respondents in both Buduk Bui and Buduk Nur mentioned that their interactions with neighbours increased as a consequence of the MHS being installed. As the electricity from micro hydro is not costly and is available all the time, people do not need to turn on a diesel generator when neighbours visit. This cheap electricity also enables the villagers to have meetings conveniently, even at night. On the other hand, 16% of respondents in Buduk Nur stated they have less interaction with people as a result of having access to electricity from the MHS, as they have entertainment at home. Respondents in Buduk Nur reported visiting the Café less frequently and stated that children now prefer to stay at home and watch TV. In Buduk Bui about 5% of the respondents mentioned that they have less interaction with people and prefer to stay at home. This preference to stay at home was also reported by some respondents (14.3%) to have resulted in fewer people going to pray at church in the evenings.

The survey found that the installation of the MHS has had no impact on the level of outmigration. According to the respondents, the lack of a high school in the vicinity is the main reason for moving away, as teenagers wanting to study beyond the primary school level have to move to other areas. After finishing their high school education, young girls tend to migrate to the city as it is easier to find work in retailing or as maids in the city. Young boys have fewer employment opportunities in the cities and prefer to stay home to help their parents with farming, fishing or hunting. However, respondents in Buduk Bui suggested that the children who live in cities are more likely to return and visit relatives now that their homes are electrified.

In both Buduk Bui and Buduk Nur only 24% of respondents' incomes were reported to have been impacted by the installation of the micro hydro systems. Those who reported that their incomes had increased were making handicrafts in the evening and the lighting from the MHS gave them a longer time to do their sewing. Some of the respondents reported that they received additional income from their work as a member of the MHS committee. In Buduk Nur, it was reported that extra income could be earned from selling meat, cold drinks and snacks for those people running a refrigerator.

7. Reported problems of the micro hydropower systems

The problems reported by the Buduk Nur committee in MHS operation and maintenance to date were both technical and non-technical. The technical problems included blocked or loose pipe work, burnt circuit boards, black-outs and reduced generating capacity during the dry season. Only in the case of the burnt circuit board did the committee need to contact the supplier. Regarding non-technical problems, the major problem was due to the number of electrical appliances used by the villagers. The number of appliances operated was often in excess of the number permitted (five 20 Watt bulbs). The main function of the Public Clinic is to keep the vaccine refrigerator operating 24 hours a day. The Clinic, however, did not benefit from the MHS as the refrigerator stopped working since September 2010 due to the unstable voltage and black-outs that often occurred during the night time as a result of overloading. As the committee has difficulty preventing the villagers from operating other appliances, the committee has encouraged the community to run appliances during the day time only, when normal demand is less.

In Buduk Bui, in general it can be said that the system has worked well since November 2008, although a few technical problems were reported. Some problems such as blocked pipes, short circuits, and black-outs, were fixed by the committee. On one occasion the help of the supplier was needed to replace a burnt circuit board. In making comparisons with Buduk Nur, it must be kept in mind that with the 250 W limits, the households in Buduk Bui had more spare capacity than the households in Buduk Nur. In other words, householders in Buduk Bui could afford to run extra appliances (other than lights and TV) and not cause power outages.

8. Discussion

The research findings have highlighted a number of issues that need discussion in the wider context of the use of micro-hydro for remote communities around the world.

The inability of the MHS, particularly in Buduk Nur, to supply constant power, especially during the dry season, is an indication of using an unreliable method to determine the project capacity at the design stage. The survey found that the MHS in Buduk Nur was not designed on the basis of long-term river flow rate data but on spot readings during a single dry season. Ideally, to guarantee that power is available all year round, the calculation of the design flow should use the minimum flow over the year [13] and a reliable flow measurement method should be used in order to look at the consistency of the flow [14]. It is also important to look at seasonal variation either across the year and preferably over a longer time, e.g. 20 years [15]. In the situation of ungauged river basins, like in Ba'Kelalan, a regional flow duration curve may be used with regard to the nearest gauged river data in the region [16, 17]. However, flow rates can vary considerably from river to river and further research is needed on the best approach for determining flow rates e.g. using remote sensing data [15]. In addition to regional flow models it is important to consider long-term climate patterns since global warming trends in which global precipitation [18] and temperature [19] are changing can also have an impact on regional river run-off and rainfall patterns [20].

Buduk Nur had an average load factor of 0.4 while Buduk Bui had a slightly higher load factor of 0.5 with both villages' peak use occurring in the evenings such that during the day there was excess power available from the system. The problem of low load factors (under 40%) in MHS has been reported in Nepal and Zimbabwe [21]. A number of success stories of MHS, where villagers were able to improve productivity and accelerate income generation by increasing the load factor and using the excess power, have been reported in Nepal [22], Indonesia [23] and Kenya [24]. Ideally, a range of loads, including low loads, should be taken into account at the planning stage in order to optimise MHS performance relative to the different types of load [25]. Another approach to increase load factor is to use demand management methods to reduce peak loads. In Nepal [26], peak loads were reduced by replacing incandescent lights with white light emitting diodes (WLED) while load factor was further improved by using excess MHS power to charge batteries. Adjusting peak loads according to seasonal supply trends is also important. For example, Nafziger [27] describes a MHS where peak load in winter was likely to occur at night for lighting and cooking devices, while in summer peak load would be in the daytime as result of using fans and refrigerators. Providing demand management training for the villagers at the beginning of the MHS project was crucial to help the community run the system effectively. In Buduk Nur, there is potential to use more power, particularly at non-peak times. However, overloading at peak times, possibly from use of unauthorised appliances, must be addressed. This would require demand management training where all the users of the system agree to a set of protocols regarding consumption. Load promotion in Buduk Bui has been more successful but the challenge for the community is to find uses that add to their quality of life. Rice-milling or rice-drying would be two examples of possible uses.

The O&M of the MHS in both Buduk Bui and Buduk Nur was a “trial and error” process. Capacity development is important in the O&M of MHS, and should be embedded in the planning of the project. Although the responsibility of O&M lies with the community most rural communities lack sufficient expertise in terms of both project management and technical skills. The Ladakh Ecological Development Group, which has set up more than 70 MHS with capacities ranging from 0.5 kW to 30 kW, reported that one of the key factors in the success of MHS was proper training for operators [28] . Comprehensive training is thus vital to support rural communities in running their O&M programs successfully.

In Ba’Kelalan, the MHS allowed some households to run washing machines and this allowed time for women, to take up income generation activities (sewing or making handicrafts and snacks). The villagers also had more access to television and radio, which helped to increase educational or health-related information. MHS in Pokharichouri, Nepal [29] and in AKRSP Chitral, Pakistan [30] have also benefited women in reducing their labour with more leisure time to interact with other community/household members or to get involved in income generating activities. Further, a major reduction in energy expenditure through use of a MHS means the community have more disposable income. A respondent in Buduk Nur stated that “now I have budget for myself (clothes, make up)”. Gonzales *et al*. reports a considerable reduction in the monies associated with energy services that previously flowed out of the community [31].

Conducting a detailed survey in a remote area is not without its difficulties. Sometimes a key informant has a lack of literacy or delegates another person to answer the questionnaire. In addition households who were not complying with the power limits set by the MHC were understandably not open to an energy audit of each appliance in the household and gave the information only by verbal exchange. The conclusions drawn from the findings of the study are thus taken in the light of these limitations.

9. Conclusion

Micro-hydro systems are widely perceived to be a sustainable means of contributing to the economic development of remote communities. Initial surveys of systems in two remote villages in the Ba’Kelalan valley in the Borneo Highlands show that economic benefits have not been as important as the amenity benefits of reliable lighting and home entertainment appliances. Due to low levels of training, the community management committees keep the systems operating by a “do nothing until there is a problem” approach. However, they were able to repairing minor problems without the need of experts. There is scope for increased training of the committee members as this could reduce the delays in repairs where technical help from outside is currently required.

The greatest problem has to do with the design of the MHS, which was based on spot reading taken during one dry season. As these spot readings did not accurately capture the flow patterns during the dry season, the system in Buduk Nur has been unable to generate during low river flow periods. A better estimation of hydrology could be attained by means of a using more rigorous and comprehensive system of river flow measurements during the dry season to accurately capture the worst case scenario, with measurements repeated over a number of years to include the yearly variation. Given the impact of climate change on rainfall, this may now be becoming even more important.

The load factor for both systems in Buduk Nur and Buduk Bui was low due to low consumption of micro hydropower during the non-peak hours. One possible way of improving load factor would be to use the micro hydro-power during the day for income generating activities such as rice-drying or rice-milling.

Free electricity from running water is often used to “sell” the benefits of micro-hydro. Consequently there is often inadequate consideration given to design and planning of the MHS electricity supply system as a whole. Some of the most overlooked factors are how to collect and manage tariffs collected from users as well as operation of the MHS. However the combination of training and an effective means of collecting funds for maintenance can help micro-hydro systems keep operating with minimum down time and maintain community faith in the system.

Further research is required to investigate the key success factors of setting an MHS for rural community. Once identified, these factors can be used in establishing guidelines for designing a sustainable MHS project in a rural community.

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Figures and Figure captions

Fig. 1. (left) Map of Borneo indicating the location of Sarawak in Malaysian and East Kalimantan in Indonesia and (right) Map indicating the six villages in Ba'Kelalan valley in Sarawak close to the border with Indonesia (The villages are: 1. Buduk Nur; 2. Long Langai; 3. Long Lemutut; 4. Long Rusu; 5. Buduk Bui; 6. Buduk Aru)

Fig. 2. Flowchart of the research methodology

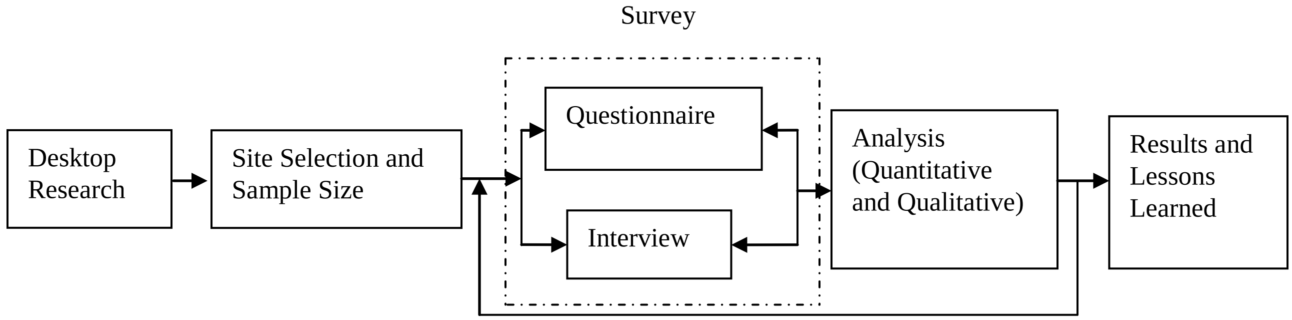

Fig. 3. Highest education level attained by respondents in Buduk Bui (left) and in Buduk Nur (right)

Fig. 4. Income sources in Buduk Bui (left) and in Buduk Nur (right)

Fig. 5. Average monthly expenditure per person in Buduk Bui (left) and Buduk Nur (right)

Fig. 6. Average monthly expenditure for main household items

Fig. 7. Breakdown of monthly average expenditure of household

Fig. 8. Distribution of average daily loads for households in Buduk Bui (left) and Buduk Nur (right)

Fig. 9. Social impact of MHS within households in Buduk Bui and Buduk Nur

Tables and Table captions

Table 1. Energy sources and average monthly consumption per household

Energy source	Kerosene (litre)	Diesel (litre)	Petrol (litre)	Wood (kg)	LPG (kg)	Candle (no. units)	0.5 Ah Dry cell battery (no. units)	MHS (kWh)
Application	Cooking	Rice milling	Transport, Lawn mowing, Power tools	Cooking	Cooking	Lighting	Torch, Radio	Lighting, Appliances
Buduk Bui	0.1	4.29	27.95	93.1	9.29	0	1.57	71.910
Buduk Nur	0	3.9	36.84	58.96	14.42	8.22	1.31	48.090

Table 2. Profile of Micro Hydro Systems in Ba’kelalan

Village	Funding	Year	Capacity	Load
Buduk Nur	Private	2004	7.5 kW	Apple Lodge and 9 households
Buduk Aru	Community based	2006	10 kW	Bible School, dormitory and staff housing
Buduk Nur	Government	2008	30 kW	Public Clinic, Church and 76 households
Buduk Bui	NGO-Community based	2008	12.5 kW	Church and 26 households
Long Langai	Government	2010	15 kW	Church and 35 households
Long Rusu	Government	2010	35 kW	Church and 19 households

[*Source: Compiled by the Author*]